

# **SCALE-UP OF CARBON/CARBON BIPOLAR PLATES DE-FC36-02AL67627**

---

**2005 DOE Hydrogen Fuel Cells &  
Infrastructure Technologies Program Review**

**David P. Haack**

**Porvair Fuel Cell Technology**

**May 18, 2006**

This presentation does not contain any  
confidential or proprietary information.

**Project ID #FC33**

# PROGRAM OVERVIEW

## *Scale-up of Carbon/Carbon Bipolar Plates*

### Timeline

- **Project Start Date:** May 2002
- **Project End Date:** November 2006
- **Percent Complete:** 90%

### Partner

UTC Fuel Cells

### Budget

50% Porvair Cost Share

	FY2005	FY2006	Program Total
<b>Porvair Contribution</b>	\$962,409	\$548,269	\$4,180,809
<b>DOE Contribution</b>	\$650,659	\$576,192	\$3,897,000
<b>Total</b>	\$1,613,068	\$1,124,461	\$8,077,809



# DOE TECHNICAL BARRIERS AND TARGETS

---



**Bipolar Plate Technical Barriers, from HFCIT Program Multi-Year Program Plan**

Technical Barrier	Units	Porvair Status 2005	Target 2010	Target 2015
Component Cost	\$/kW	Volume Dependent	\$6	\$4
Component Weight	kg/kW	0.36	< 1	< 1
Hydrogen Permeability	cc/cm ^2/sec (x10^-6)	< 5	< 2	< 2
Conductivity	S/cm	> 600	>100	> 100
Resistivity & Contact Res.	ohm/cm ^2	< 0.02	< 0.01	< 0.01
Flexural Strength	MPa	> 34	> 4 (crush)	> 4 (crush)

# PROJECT OBJECTIVES 2005

---

<b>Overall</b>	<ul style="list-style-type: none"> <li>* Develop carbon/carbon bipolar plate manufacturing process</li> <li>* Evaluate product stability to 1000 hours</li> <li>* Investigate next-generation manufacturing techniques</li> <li>* Demonstrate product performance in fuel cell testing</li> </ul>
<b>2005</b>	<ul style="list-style-type: none"> <li>* Perform detailed manufacturing demonstration study</li> <li>* Investigate manufacturing process improvements</li> <li>* Evaluate product tolerance achievement for complex geometries</li> <li>* Develop plate sealing method</li> <li>* Begin investigation into rapid forming methods</li> </ul>
<b>2006</b>	<ul style="list-style-type: none"> <li>* Demonstrate fuel cell operation with net shape molded plates</li> <li>* Optimize plate sealing method</li> <li>* Complete manufacturing process improvements</li> <li>* Complete rapid forming method investigations</li> <li>* Final product cost analysis</li> </ul>



# TECHNICAL APPROACH

## 2005 OBJECTIVES

---

- **Develop Net-Shape Molding Technology**
  - Optimize materials
  - Develop measurement methods
  - Evaluate varied molding geometries and characterize material shrinkage
  - Determine net shape molding process capability
  - Improve plate hydrophilic/hydrophobic characteristics
- **Develop and Evaluate Sealing Method**
  - Materials development
  - Test method development and implementation
  - Product stability evaluation

# **TECHNICAL APPROACH**

## **2005 OBJECTIVES**

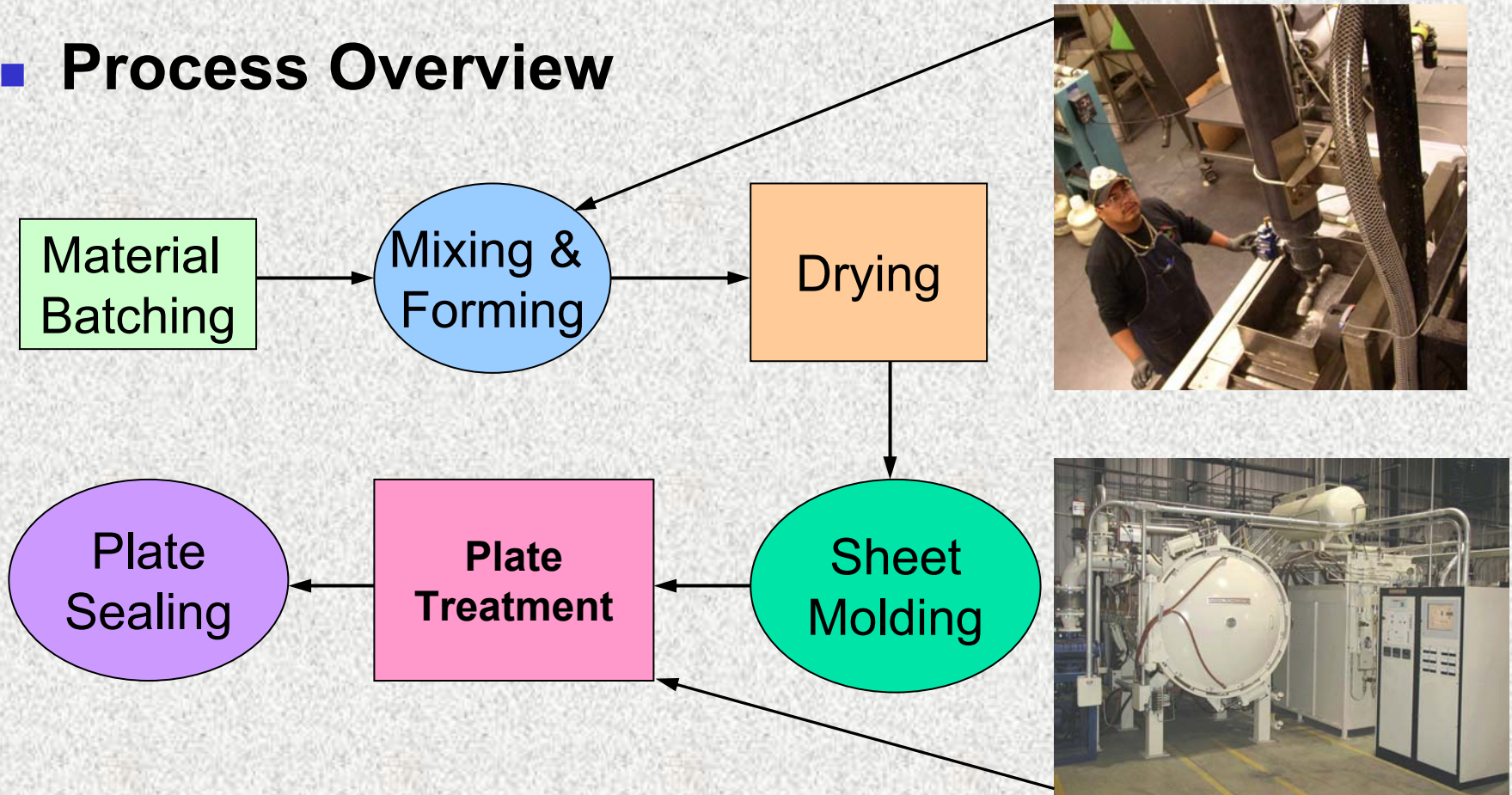
---

- **Manufacturing Demonstration**
  - Operate system, collect relevant data
  - Examine data statistically
- **Optimize Manufacturing Process**
  - Materials development
  - Property measurement and development
  - Process control improvements
  - Process improvement activities
    - FMEA
    - Quality plan
    - Lean events



# TECHNICAL ACCOMPLISHMENTS

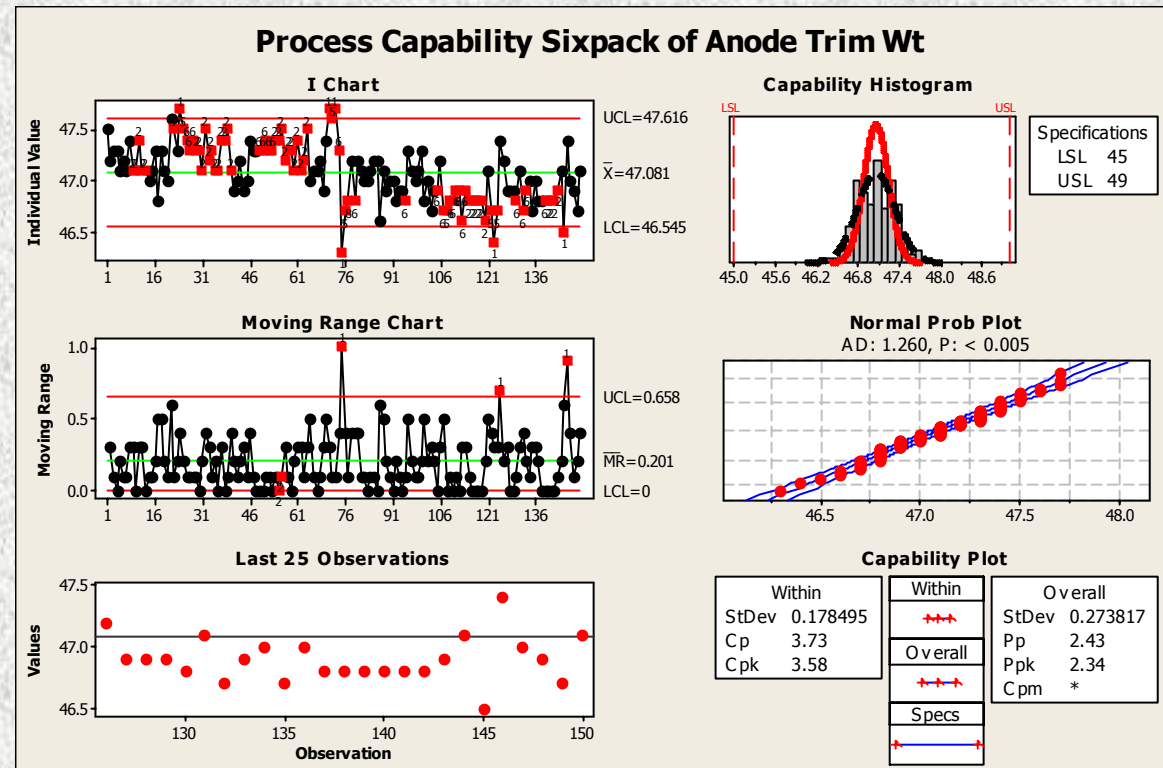
## ■ Process Overview



# TECHNICAL ACCOMPLISHMENTS

Late 2005 Capability

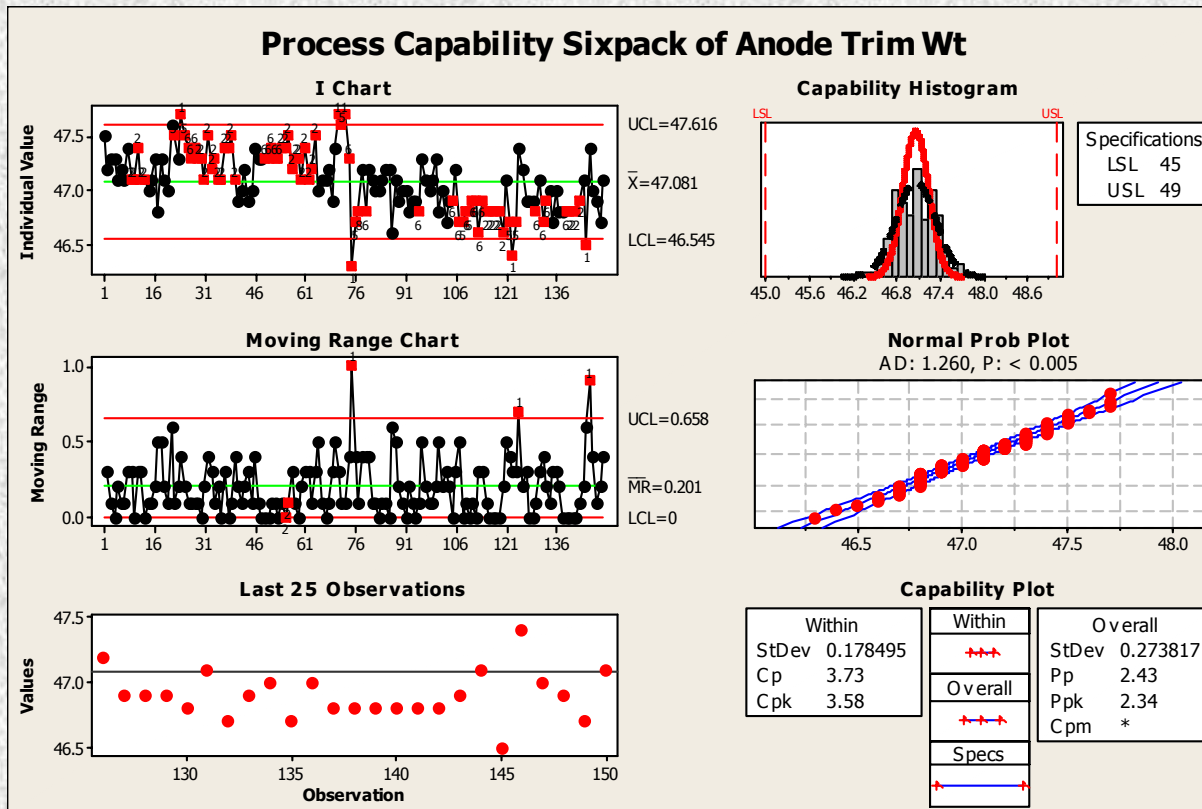
- **Process Demonstration**
  - Net-shape molded bipolar plates – anodes and cathodes
  - Data shows key variable process capability





# TECHNICAL ACCOMPLISHMENTS

## ■ Final Preform Trim Weight – Key Process Variable

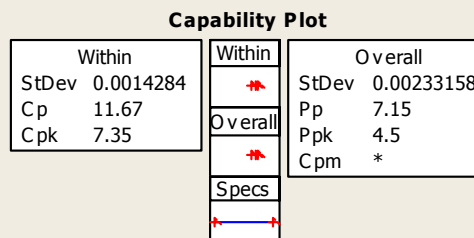
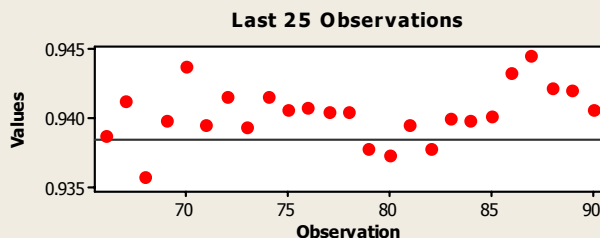
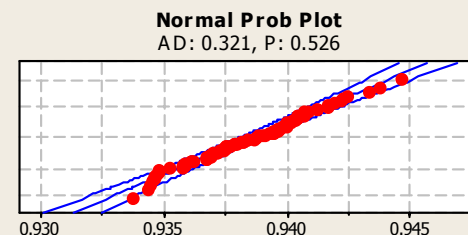
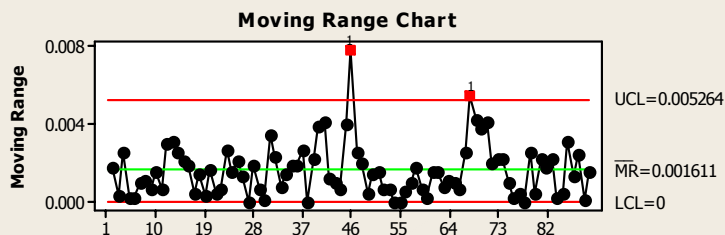
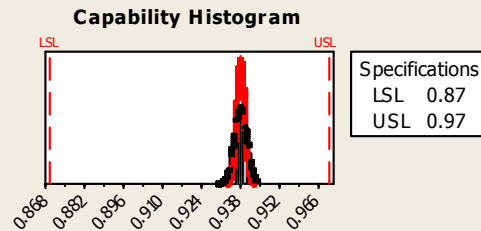
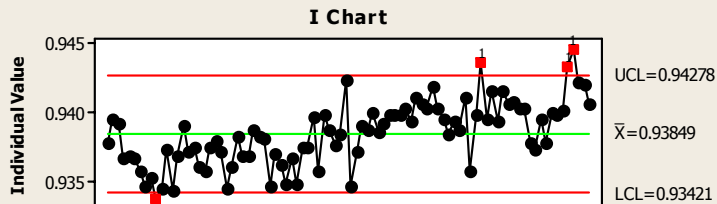


Trim sheet weight consistency drives product consistency, and is the single most important measurable in our process. We demonstrated Cpk's ~2.

# TECHNICAL ACCOMPLISHMENTS

## ■ Plate Geometry – Final Thickness

**Process Capability Sixpack of AvgThickness\_all4**



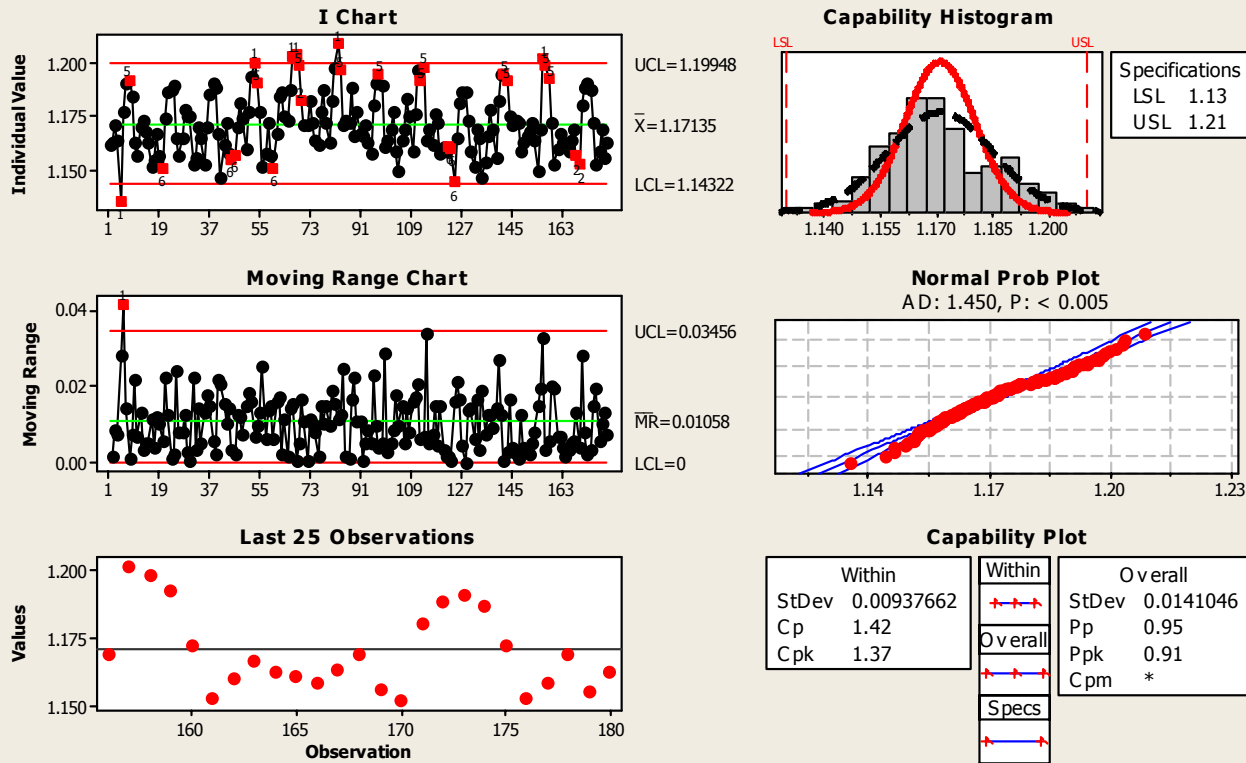
**Final plate thickness. Measured in 10 positions on plate. Capability is very good relative to specifications, but off center. Adjustment made to re-center part thickness.**



# TECHNICAL ACCOMPLISHMENTS

## ■ Within Plate Uniformity

Process Capability Sixpack of PressDen



Data shows coupon consistency from as-molded plates (15 equal size coupons measured per plate evaluated). This data shows that we have ~0.8% standard deviation in our product (which exceeds our long-term goal of 1%).

# TECHNICAL ACCOMPLISHMENTS

## ■ Channel Dimensions

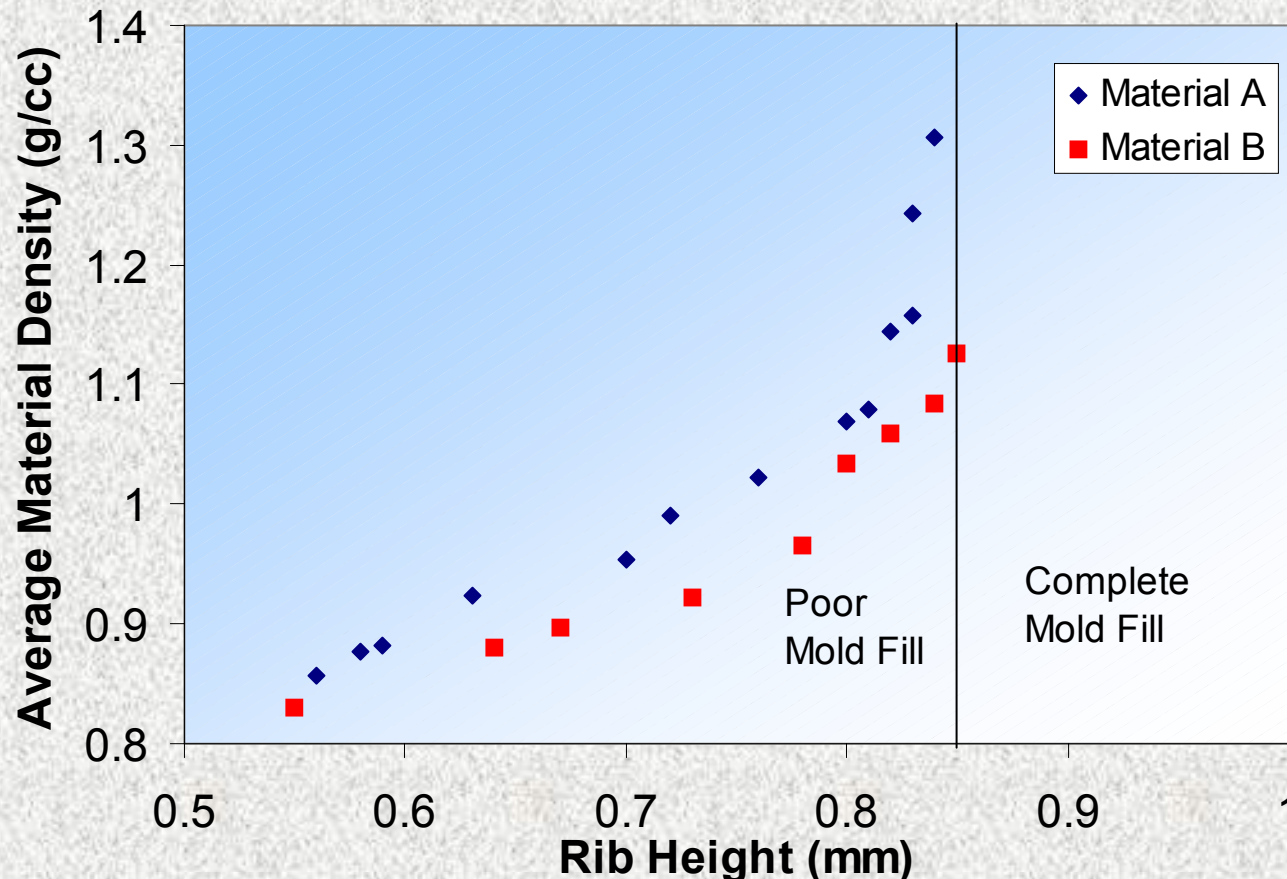
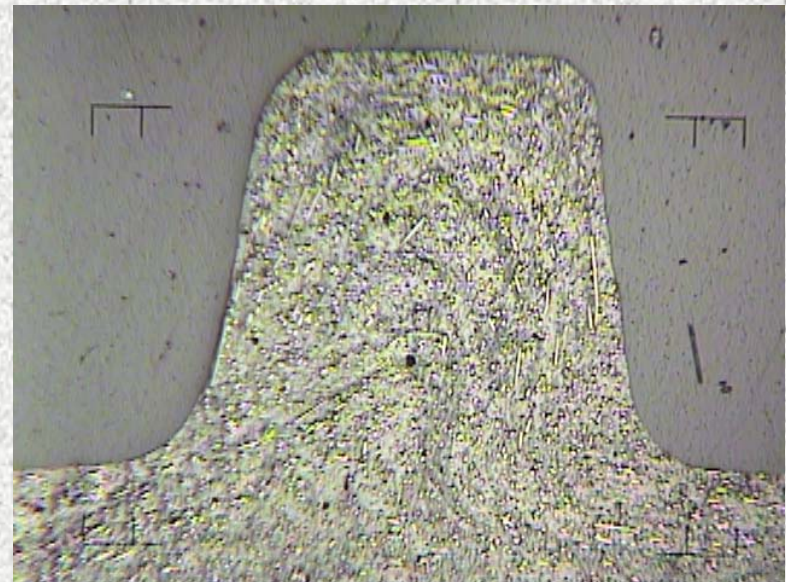
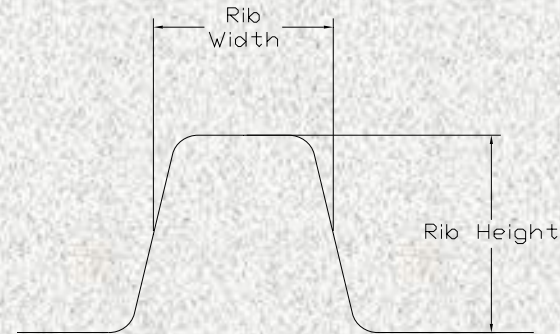


Chart shows rib height vs. material density. Materials development resulted improved mold fill at lower overall product density – better mold fill at lower molding pressures.



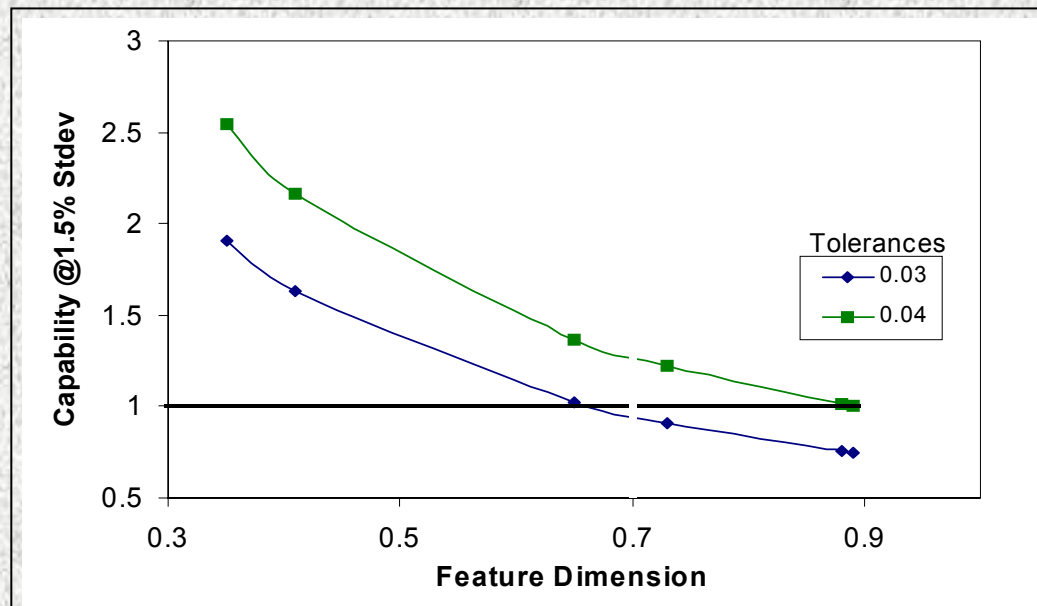
# TECHNICAL ACCOMPLISHMENTS

- **Channel Dimensions**
- **Material Shrinkage Characterization**
  - Material orientation impacts material shrinkage
  - This shrinkage was characterized for a wide range of channel dimensions
  - Data used to design new mold dies



# TECHNICAL ACCOMPLISHMENTS

- **Channel Dimension – Capability Analysis**
  - Better capability at smaller feature dimension
  - Capability marginal at larger feature size with typical customer tolerances





# TECHNICAL ACCOMPLISHMENTS

---



## ■ Product Sealing

- Significant work done to improve product sealing
  - Defining sealing tests (full plate small sample)
  - Reducing contact resistance
  - Reducing hydrogen permeability
  - Evaluating product durability and lifetime
- Sealing work on-going

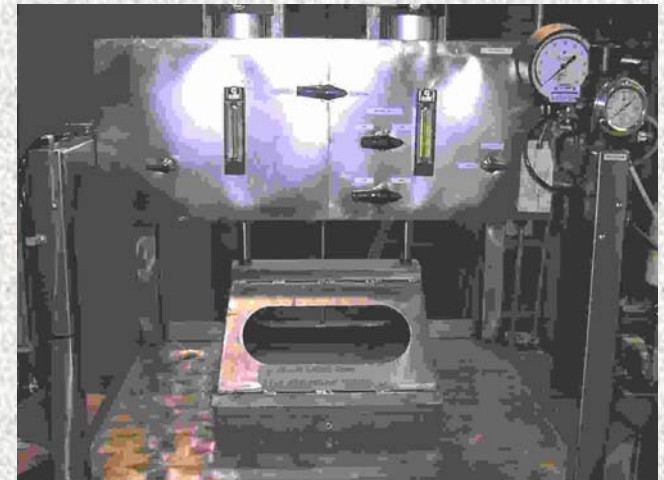
# TECHNICAL ACCOMPLISHMENTS

## ■ Sealing Results

- Hydrogen perm  $\sim 2 \times 10^{-5}$  cc/cm<sup>2</sup>/sec @ 30 psi, room temp.
- Seal is stable for more than 500 hours in 0.1M sulfuric acid at 80C

## ■ Seal Testing

- Large scale is coarse test and checks for presence of flow in a fine variable area flow meter
- Small scale test is hydrogen test following ASTM 1434-82





# TECHNICAL ACCOMPLISHMENTS

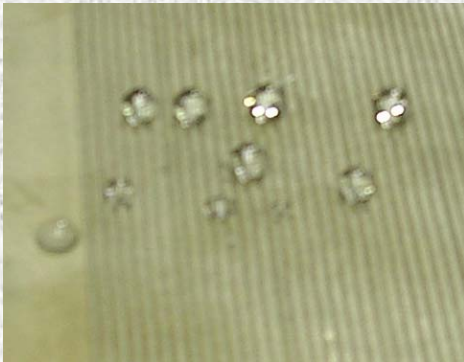
---



- **Wettability Treatments**
  - **Investigations performed on enhancing the surface water wetting characteristics**
    - **Hydrophobic and hydrophilic treatments investigated**
    - **Durability evaluated by high temperature sulfuric acid soak**

# TECHNICAL ACCOMPLISHMENTS

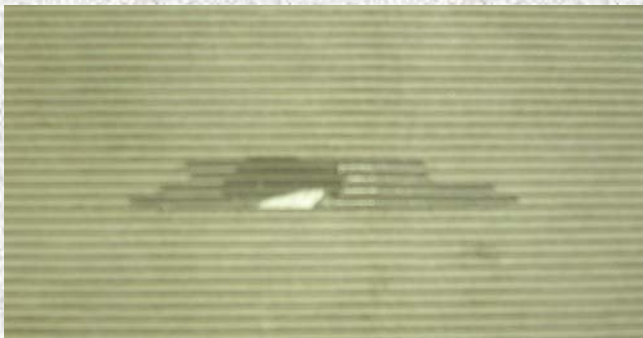
---



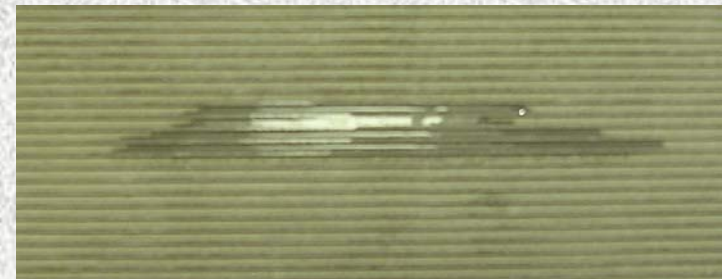
Hydrophobic surface  
before sulfuric acid soak



Hydrophobic surface  
after sulfuric acid soak



Hydrophilic surface



Hydrophilic surface after sulfuric  
acid soak



## **FUTURE WORK 2006**

---

- **Investigate Next-Generation Processes**

- Aimed at reducing process time from minutes per plate to seconds per plate
- Focused at the molding and final treatment processes

- **Demonstration of Fuel Cell Performance with Net Shape Molded Stack**

- Stack testing currently underway (approximately 1800 hours accumulated at the time of this presentation)

## **FUTURE WORK 2006**

---

- **Complete Process Improvement Activities**
  - Generate final QA plan, FMEA
  - Perform final lean event to eliminate non-value-added steps from process
- **Complete Sealing Development**
  - Finalize evaluation of product durability
  - Finalize development of hydrophobic surface treatment
- **Final Product Cost Analysis**
  - Perform final product manufacturing cost evaluation
  - Evaluate final product capability relative to DOE targets



# REVIEWERS COMMENTS

---

- **Cost Model Not Clearly Explained**
  - Detailed explanation of cost model would have taken longer than the time allotted for the presentation
  - Focused upon results of cost model instead
- **Reliance on single partner will bias the project**
  - Most of our work done with UTC Power
  - Several customers have/are evaluating our sealed plate materials
  - We find FC manufacturers are focusing upon areas other than bipolar plates at present. While there is interest, there is not a strong drive for customers to devote significant resources.
- **Project directed toward commercialization of this technology. Limited public knowledge developed in this project**
  - Our project includes 50% cost share
  - Specifics of program are proprietary

## **PRESENTATIONS/PUBLICATIONS**

---

- **Other than the 2005 DOE Fuel Cell program review, and the 2005 Tech Team review, no other presentations or publications were made in 2005 from work resulting from this program**



# CRITICAL ASSUMPTIONS/ISSUES

---

- Relevance of Sulfuric Acid Durability Testing
  - Materials known to be used with success in fuel cells do not pass testing with hot sulfuric acid – is test too rigorous?
- Impact of Moderately Hydrophobic Surface
  - Customers can not clearly indicate impact or difference in performance between a hydrophobic or hydrophilic surface
- Customer Channel Tolerances are Very Tight
  - Typically +/- 0.03 mm (+/- 1 mil)
  - What is the impact of less restrictive tolerances? Wider tolerances may not impact performance, but will make the manufacturing process much more capable